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Investigation of Composite Cloud Fields as Applied to Tropical Storm Forecasting

THOMAS J. KEEGAN

13 June 1977

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AIR FORCE SYSTEMS COMMAND, USAF

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FOR THE COMMANDER

John Howard

Chief Scientist

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This report reviews the work reported earlier in AFGL-TR-76-0170, Cloud Distributions as Indicators of Tropical Storm Displacement, by the same author, on the application of composite cloud imagery to the forecasting of tropical storm motion. Several additional techniques that were tested briefly for application to typhoon specification and forecasting are discussed and evaluated. Animations of 12-hour infrared images did not suggest anything useful within the limited time available for analysis. The technique, however, should be comprehensively tested with data of better time and

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spatial resolution. Infrared composites appeared to be less useful than visual composites. The increased detectability of thin cirrus clouds in the infrared masked the significant cloud features. An attempt to duplicate Dvorak's relationships between peak wind speed and the central and banding features of typhoons by compositing storms of similar intensity failed. The fine details Dvorak could distinguish in individual storms were destroyed by the compositing process. Objective analysis of satellite imagery of typhoons is seriously handicapped by the limited archive of digital data.

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Investigation of Composite Cloud Fields as Applied to Tropical Storm Forecasting

I. INTRODUCTION

The Joint Typhoon Warning Center (JTWC) on Guam is responsible for locating, describing and forecasting tropical storms in the western Pacific Ocean. The reconnaissance aircraft support for this work has diminished in the past and will be reduced even more in the future. In response to Air Weather Service (AWS) field requirements to compensate for these losses, an investigation of the application of meteorological satellite imagery to the typhoon reconnaissance and forecasting problem was undertaken. Results were achieved that show much promise for practical application and they are reviewed briefly in the next section. The Man-computer Interactive Data Access System (McIDAS) proved to be a very effective tool for applying the composite-analysis technique to cloud pictures. Changing field requirements and research priorities brought this investigation to a premature close. There was, however, a limited amount of time to conduct cursory examinations of some of the recommendations made in the first report.

This report, then, briefly reviews the previous work, summarizes some brief extensions of that work, evaluates the approaches used and contains some suggestions for those working on similar problems.

(Received for publication 10 June 1977)

2. REVIEW OF PAST EFFORT

The primary source of satellite imagery available to the forecasters on Guam is the Department of Defense satellite, DMSP. It would seem reasonable, then, that this study would have been based on data from that satellite system. Unfortunately, there is no digital archive kept by AWS and a practical working arrangement to save and transfer current data to AFGL could not be devised. The lack of an archive also applies to the geosynchronous satellite data. The only archive of digital satellite data is that from the NOAA series starting in 1973. These data have been processed into a mapped format and are of reduced resolution. Despite this handicap, promising results were generated with these data and reported by Keegan.[1]

The approach used in this study was based on the analysis of composite cloud fields. In this technique, one first selects a number of satellite pictures containing storms which have some feature in common, such as the direction they are going to take in the next 24 hours. A composite is constructed by first identifying every data point in each image by its location relative to the storm center. The "time" average of the brightness values at each point is then calculated and this composite brightness field is displayed on the McIDAS. Thus one would expect to see a very bright mass of cloudiness within a hundred or so miles of the center of the composite storm. If, on one hand, clouds were distributed randomly outside the immediate storm area, the rest of the composite picture would be gray representing the averaging of clear and cloudy conditions at each of the data points. If, on the other hand, some areas of cloudy or clear skies were distributed systematically outside the storm environment, the composite would show bright or dark areas at these locations. Tests are then made to establish whether the locations of these clear and cloudy areas change when composites are generated for storms moving in other directions. If the composites are substantially different, the spatial distribution of cloudiness outside the immediate storm area can be expected to have forecast value. The power of the composite technique lies in its ability to mute the random details and to reinforce the significant features associated with or preceding a specific event.

Figure 1 is an example of composite imagery. The images cover roughly the quadrant of the northern hemisphere from 90°E to 180°. The arrows indicate the center of the storms that went into each composite. The storms were all located between 15°N and 20°N; 120°E and 125°E. The five storms in Figure 1a were all headed in a general westerly direction while the four storms in Figure 1b

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1. Keegan, T.J. (1976) Cloud Distributions as Indicators of Tropical Storm Displacement, Environmental Research Papers, No. 575, Air Force Geophysics Laboratory (AFGL-TR-76-0170)

Figure 1a. Composite visual images of typhoons in the area bounded by 15° N, 20° N; 120° E, 125° E. Arrow indicates composite center of 5 storms headed toward the west.

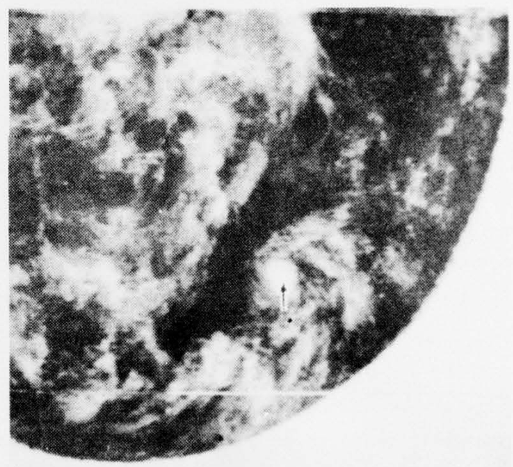


Figure 1b. Composite visual images of typhoons in the area bounded by 15° N, 20° N; 120° E, 125° E. Arrow indicates composite center of 4 storms headed toward the northwest.

were headed northwesterly. The differences between the composites are apparent. In the case of the westerly moving storms, there is a band of cloudiness that extends northeastward into the area affected by the middle latitude frontal cloudiness. The more northerly moving storms are associated with a cloud-free zone that extends from the northwest through the northeast quadrants, with more extensive cloudiness in the east and southeast quadrants. These cloud features are common to similar moving storms in other parts of the western Pacific Ocean.

Other relationships between storm cloudiness and motion were suggested in the previous work. These apparent relationships were internally consistent, but there was not a large enough data sample to establish the significance of the results.

Recommendations in the above referenced report included reanalyzing the storms in the infrared format. This would provide twice as many samples, introduce a meteorologically significant variable, temperature, into the analysis and permit an attempt at a rudimentary animation analysis. These recommendations, as well as an attempt to relate wind speed to the cloud field, were examined in the brief time available for "wrapping up" this investigation.

3. ANALYSIS

3.1 Animation

One of the most dramatic techniques used to display satellite imagery is that of creating an animated movie loop from a sequence of half-hourly geosynchronous satellite pictures. Many features that are not noticed or are ambiguous on a single frame become easily identifiable when viewing these loops. For example, clouds are readily stratified into height categories by their rate of motion, and the gradual brightening of the background caused by the development of small clouds is more noticeable in animation than in a succession of still pictures. Early in this investigation, it was observed that a motion effect could be achieved with the NOAA archive visual data displayed once each 24 hours. Accordingly, a recommendation was made to check out the potential of animation using the infrared data that are available at 12-hour intervals.

Seven loops of sequences ranging from 5 to 20 days were assembled. Time limitations and some technical problems curtailed this investigation before any realistic estimate of the value of the technique could be made.

The following comments are presented for those who may have an interest in following up on this work since the animations do have a continuity that is reasonably smooth and realistic.

a. So much action is taking place simultaneously that concentration easily becomes diluted.

b. It is difficult to compare the activity in one sequence with that in another sequence mentally.

c. In view of the type of difficulties mentioned in (a) and (b) above, animations might be used more effectively to verify and modify the large-scale circulation features depicted on the data-poor weather charts of the oceanic areas.

The revised circulations resulting from these modifications should then be evaluated for their effects on the original forecast of storm motion and development.

d. The use of animated imagery should not be categorically dismissed. A 12-hour gap is a long interval and only the largest features survive. Better time and space resolution may provide a more apt data base for this type of approach.

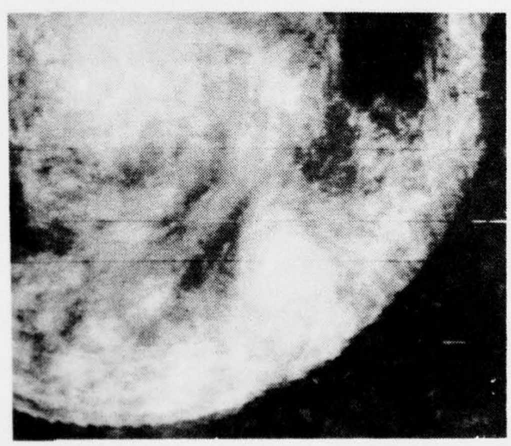
3.2 Infrared Analysis

The work reported earlier used only visible data. One of the suggestions for future work was to use the infrared data which was available every 12 hours and might show diurnal changes that would help emphasize distinctions between storm classes. Further, the infrared display usually appears simpler to the eye and, of course, the image brightness has physical significance in terms of temperature.

Infrared composites were generated for all of the cases discussed in the first report. Figures 2a and 2b are the infrared counterparts of Figures 1a and 1b. The key features discussed in relation to Figure 1 are present but do not stand out as strongly as they do in the visible. Figures 2c and 2d are the infrared composites for the period 12 hours after Figures 2a and 2b, respectively. As can be seen, there are no differences between the day and night infrared data that suggest that any new information might be available.

On the basis of this limited test, with data of this type, it appears that visible data are preferable to infrared data in composite analysis.

Figure 2a. Composite is the infrared image corresponding to Figure 1a.



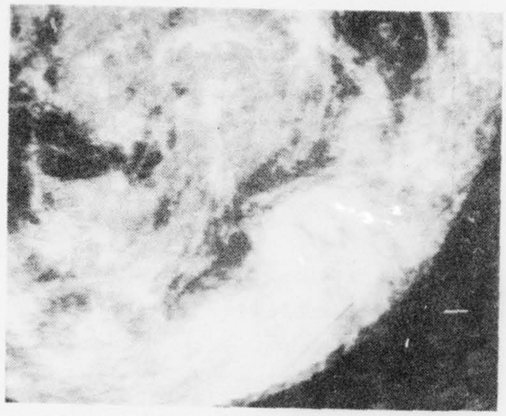


Figure 2b. Composite is the infrared image corresponding to Figure 1b.

Figure 2c. The infrared composite for the data observed 12 hours after that in (2a).

Figure 2d. The infrared composite for the data observed 12 hours after that in (2b).

3.3 Wind Speed Analysis

Dvorak[2] developed a systematic approach to the specification and forecasting of the peak wind in tropical storms based on visual features in the satellite images. Dvorak employed what is basically the composite technique. However, all the compositing and identifications of key features were done in his memory and not on a computer. He then developed a descriptive model of the key features for the guidance of others.

What Dvorak did subjectively should be an ideal job for the McIDAS used as an image compositor. Accordingly, a brief test to establish whether the Dvorak technique could be duplicated and possibly improved by objective compositing on the McIDAS was initiated to wind up the study. As with the storm motion work, the data were first stratified by location. Compositing was restricted to storms centered within the same 5-degree latitude-longitude box. This avoided the practical difficulties involved in shifting the satellite data, which had been rectified to a polar stereographic format, to areas of different map scale, and eliminated varying surface characteristics.

Figure 3 shows composites of storms between 15°N and 20°N and 110°E and 115°E. Peak speeds in Figure 3a are from 45 to 55 kts and the composite is made up of 4 storms. In Figure 3b, 5 storms ranged between 65 and 75 kts and the 2 storms of Figure 3c had speeds of 70 kts. There is nothing about these

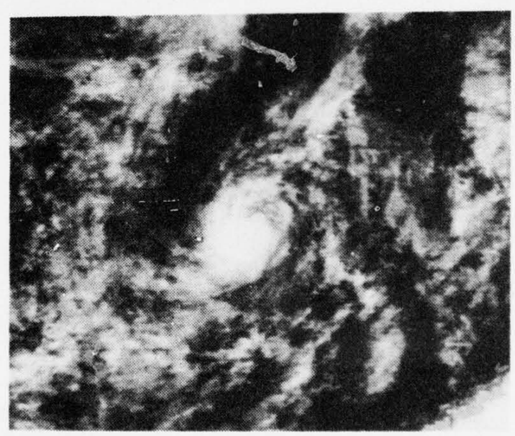


Figure 3a. Composite visual images of storms bounded by 15°N, 20°N; 110°E, 115°E, 4 storms with peak wind between 45 and 55 kts. (Scale is larger than that used in Figures 1 and 2).

2. Dvorak, V.F. (1975) Tropical cyclone intensity analysis and forecasting from satellite imagery, Mon. Wea. Rev., **103**: 420-430.

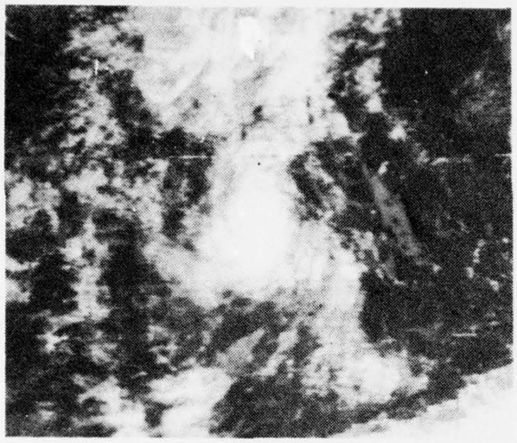


Figure 3b. Composite visual images of storms bounded by 15° N, 20° N; 110° E, 115° E, 5 storms with peak wind between 65 and 75 kts. (Scale is larger than that used in Figures 1 and 2).

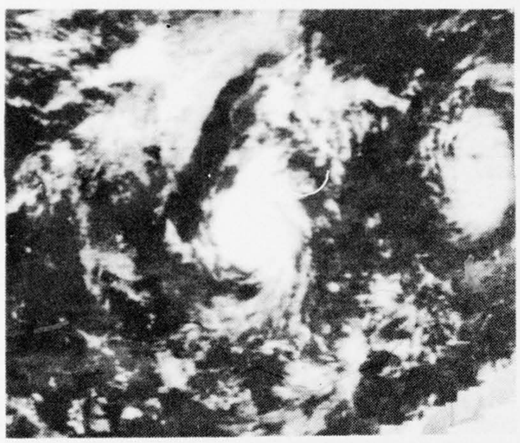


Figure 3c. Composite visual images of storms bounded by 15° N, 20° N; 110° E, 115° E, 2 storms with peak speeds of 70 kts. (Scale is larger than that used in Figures 1 and 2).

three composites that suggests any of the characteristic features defined by Dvorak. This also held true for many other composites in all speed ranges in all parts of the western Pacific Ocean.

It is not surprising that this negative result occurred. It represents an example of the limitations of the composite technique. Dvorak looked at individual storms in which he could observe and measure the characteristics of the eye, central overcast and banding. He was then able to relate the sizes and shapes of these features to storm intensity. When the data are bulk-processed, as they are in compositing, the subtle shadings and textures that define these

features are blended indiscriminately into a featureless average. The composites just show the extent of the total cloudiness associated with the storm and that is not related to storm intensity. Examination of the corresponding infrared images reveals nothing different except for the increased detectability of thin cirrus clouds common to the infrared imagery. It does not seem very likely that improved imagery resolution would have brought out any significant features of the type catalogued by Dvorak. Unless size, location and orientation of the central and banding features were much more organized than even Dvorak expected, the compositing process would destroy the important details.

4. CONCLUSION

4.1 Summary

The analysis of animations of 12-hour infrared data provided no insight into tropical storm characteristics. This is not to say that the technique itself is without merit. With more time, or better spatial and temporal resolution, this type of analysis might prove very useful.

Infrared composites, on the scale analyzed, were less useful than visual composites. One major weakness with infrared compositing is the increased detectability of the ubiquitous thin cirrus cloudiness in the infrared. The effect of the cirrus is to mask the more significant cloud features.

The characteristics of tropical storms that are affected by features of the synoptic scale circulation are reflected in the synoptic scale cloudiness. Thus, relationships were found between 24-hour storm movement and the large-scale cloud field. Conversely, characteristics that would be affected by the details of the storm dynamics are reflected in the details of the cloud field in the vicinity of the dynamic event. Since these events are comparatively small in scale and have no preferential location relative to the storm center, any manifestation of them in the cloud field is subdued. The compositing technique, as applied in this study, was not sensitive enough to extend or even repeat the subjective analysis of Dvorak.

4.2 Recommendations

This study has been hampered from the beginning by the unavailability of a suitable data sample. Neither DMSP, GOES nor full resolution NOAA data were available in digital format in the quantity required to conduct a synoptic climatological investigation. In fact, getting DMSP tapes for a case study or two has to await the occurrence of new storms, as only a one-week backlog of data are

maintained at A. F. Global Weather Central before the tapes are reused. There still is no suitable archive available for this type of study. The assembling of a high-quality digital archive of satellite data by the meteorological agencies cannot be started too soon.